Section: Emergency Medicine

Original Research Article

FLUID BALANCE: REGULATION OF WATER INTAKE AND LOSS

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Received *: 23/01/2026*
Received in revised form *: 22/02/2026*
Accepted *: 25/02/2026*

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DOI: 10.70034/ijmedph.2026.1.353

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (1); 2029-2033

ABSTRACT

Background: Water constitutes approximately 45–75% of total body weight and is essential for physiological functions including metabolism, temperature regulation, and tissue maintenance. In critically ill, mechanically ventilated patients, fluid homeostasis is disrupted due to reliance on intravenous fluids and impaired physiological responses. The objective is to derive an optimal input to output ratio, to aid in fluid administration of critically ill patients.

Materials and Methods: A prospective observational study was conducted over 12 months at HKE, Basweshwar teaching and general Hospital Kalaburgi. The study included adult patients admitted to the ICCU and CCU who were intubated for medical reasons and mechanically ventilated for over 24 hours. Patients who completed an SBT using a T-piece or CPAP mode and underwent their first (index) extubation were included.

Results: Among categorical variables such as gender, primary diagnosis, type of SBT, diuretic use, and dialysis, no significant associations were found with extubation outcomes. However, cumulative fluid balance showed a statistically significant difference between extubation success and failure groups.

Conclusion: Cumulative fluid balance emerged as a potential key factor in predicting extubation outcomes, whereas the fluid input/output ratio alone did not serve as a reliable predictor.

Keywords: Cumulative fluid balance, input/output ratio, critically ill, fluid management, spontaneous breathing trial.

INTRODUCTION

Fluid balance is a state of equilibrium where the body's intake matches its output. This balance is regulated by mechanisms involving thirst, kidney function, and hormonal control to maintain homeostasis. Water intake is influenced by thirst, habits, and socioeconomic factors. Additionally, water comes from food and is produced through the metabolic oxidation of fats and carbohydrates.[1]

Fluid intake is primarily controlled by thirst, which individuals perceive as dryness in the mouth and throat due to decreased salivary secretions. A subtle change in serum osmolarity is detected by osmoreceptors in the hypothalamus, relayed to the cerebrum, and consciously experienced as thirst. The osmoreceptors in the anterior hypothalamus shrink in response to dehydration-induced hypertonicity, with just a 1-2% rise in serum osmolarity triggering the thirst response. In conditions involving extracellular fluid loss, such as hemorrhage and gastrointestinal loss, baroreceptors in the carotid sinus and aortic arch—along with volume receptors in the cardiac atria and great vessels—stimulate the thirst center. This mechanism activates only when plasma volume drops by more than 10%. The renal system also helps detect volume loss through kidney volume receptors, which activate the renin-angiotensin system to preserve fluids. These two mechanisms typically work together, as seen during excessive sweating from strenuous exercise or in tropical climates. Since sweat is a hypotonic fluid, its excessive loss increases serum osmolarity and reduces plasma volume, leading to both intracellular and extracellular fluid loss.[1-4]

Emerging research from a variety of sources suggests that ICU patients who achieve a negative fluid balance have better results in terms of morbidity and death. In sepsis and kidney disorders,

a positively tilting fluid balance is linked to an increased risk of mortality. Moreover, it has been demonstrated to lengthen mechanical ventilation times and cause pulmonary problems. Pathophysiologically, a positive fluid balance will lead to an increase in capillary leakage, which will increase lung volume and result in a decrease in lung compliance, which will cause respiratory distress during the attempt at spontaneous breathing and immediately after extubation, ultimately leading to extubation failure. As a result, this study is planned as a prospective observational study to provide more knowledge about fluid balance in critically sick patients and to help with the appropriate titration of resuscitative fluids following first resuscitation.[5-7]

MATERIALS AND METHODS

This prospective observational study was done among Intubated patients admitted to ICCU and CCU of HKE, Basweshwar teaching and general Hospital Kalaburgi from Jan 2025 to December 2025. The study was conducted in compliance with the ethical standards of the Institutional Ethical Review Board.

Inclusion Criteria

- All the patients aged older than 18 years.
- Patients intubated for medical cause.
- Invasive mechanical ventilation for >24hours.
- Successful completion of SBT with T piece trial or by CPAP mode.
- Only first extubation (index extubation) will be considered in the study.

Exclusion Criteria

- Already intubated at time of admission.
- Extubated within one day of admission.
- Self extubations.
- Post-Op cases
- Trauma or surgical cases.
- Long duration intubation leading to tracheostomy

Sample Size Calculation: With anticipated Sensitivity and specificity For Extubation failure 60% and 59.5% respectively, considering the prevalence of Extubation failure 24% (ref), at precision of 1% and 95% confidence, the required sample size is 385.

Formula used is—

$N=(Z^2 P(1-p))/\Delta^2$

N ill be (a+c) if we use sensitivity as p

N= (a+c)/Prevalence

Data Collection Method

Baseline data -- Day of admission, age, sex, underlying acute and chronic disorder.

For all extubation following successful SBT the following data were collected:

- Total duration of mechanical ventilation
- Cumulative Fluid Input
- Cumulative Fluid Output
- Net Cumulative Fluid Balance
- Net Cumulative fluid Input to Output ratio
- Use of diuretics
- Use of dialysis
- Application of NIV support or reintubated, for extubation failure group.

Statistical Analysis: The data obtained will be entered in a Microsoft Excel sheet, and statistical analysis will be performed using JMP Pro 16 and statistical package for the social sciences (Version 20). Results will be presented as Mean (Median) ±SD, inter quartile range, counts and percentages and diagrams. Categorical variables will be compared using Chi square test. ROC Curve analysis will be applied to find optimal input output ratio along with Sensitivity, Specificity. $p<0.05$ will be considered statistically significant. All statistical tests will perform two tailed.

RESULTS

A total of 370 patients who underwent mechanical ventilation followed by extubation were included in the study. The majority of the study population were male, comprising 255 patients (68.9%), while females accounted for 115 patients (31.1%). The most common primary diagnosis leading to mechanical ventilation was respiratory disease, observed in 111 patients, followed closely by cardiovascular disease in 104 patients. Other primary disease categories included general or miscellaneous conditions (n = 63), neurological conditions (n = 55), and renal diseases (n = 37).

Regarding comorbidities, 158 patients (42.7%) had no known comorbid conditions. Among those with comorbidities, cardiovascular disease was the most prevalent (n = 60), followed by diabetes mellitus (n = 39) and respiratory comorbidities (n = 31). The remaining patients had neurological, renal, or multiple coexisting comorbid conditions.

Two types of spontaneous breathing trials (SBTs) were employed prior to extubation. The T-piece trial was used in 196 patients, whereas 174 patients underwent SBT using CPAP mode. Diuretic therapy was administered to 74 patients, while 296 did not receive diuretics during the peri-extubation period. Additionally, 45 patients required dialysis during their ICU stay, whereas the majority (n = 325) did not.

The overall extubation success rate was high, with 304 patients (82.2%) successfully extubated. Extubation failure occurred in 66 patients (17.8%). Among those who failed extubation, 39 required reintubation, while 27 were transitioned to non-invasive ventilation (NIV) as an alternative post-extubation support strategy.

An independent samples analysis was conducted to compare key demographic and clinical parameters between two groups, likely corresponding to extubation outcomes (success vs. failure), using the

Mann-Whitney U test due to non-normal distribution of variables.

The comparison of patient age between groups yielded a Mann-Whitney U statistic of 9552 with a p-value of 0.542, indicating no statistically significant difference in age between the groups.

Cumulative Fluid Input: The cumulative fluid input showed there was not statistically significant. While fluid input volumes varied between groups,

Duration of Mechanical Ventilation: For the duration of mechanical ventilation, the analysis indicating no significant difference in the length of mechanical ventilation between the groups.

Cumulative Fluid Balance: A statistically significant difference was observed in cumulative fluid balance between the two groups (a p-value < 0.05). This finding suggests that patients with different extubation outcomes had significantly different net fluid balances.

Cumulative Fluid Output: The comparison of cumulative fluid output indicating no statistically significant difference. Thus, fluid output alone may not be a key factor differentiating outcomes in this sample.

Fluid Input/Output Ratio: The fluid input/output ratio was not statistically significant. Although this metric accounts for the relationship between fluid input and output, it did not differ meaningfully between the groups in this analysis.

Among all variables analyzed, only cumulative fluid balance demonstrated a statistically significant difference between groups. This suggests that net fluid status may play a critical role in extubation outcomes and could serve as a valuable parameter in clinical decision-making.

Table 1: Comparison of demographic and clinical characteristics between extubation success and failure groups

Group Descriptives				
	Group	**N**	**Mean**	**SD**
Age	Extubation Failure	66	46.98	21.222
	Extubation Success	304	48.49	20.317
Cumulative Fluid Input (mL)	Extubation Failure	66	12452.11	7504.344
	Extubation Success	304	11802.85	9164.727
Duration of Mechanical Ventilation (Days)	Extubation Failure	66	5.74	2.544
	Extubation Success	304	5.76	2.605
Cumulative Fluid Balance (mL)	Extubation Failure	66	1613.03	2072.283
	Extubation Success	304	1058.93	1730.252
Cumulative Fluid Output (mL)	Extubation Failure	66	10839.08	6534.971
	Extubation Success	304	10743.92	8832.422
Fluid Input/Output Ratio	Extubation Failure	66	1.16	0.150
	Extubation Success	304	1.13	0.150

The study population of 370 patients was stratified into two groups based on extubation outcomes: extubation success (n = 304) and extubation failure (n = 66). Group comparisons were performed using descriptive statistics and chi-square tests to evaluate associations across demographic and clinical variables.

Age: The mean age of patients in the extubation failure group was 46.98 years (SD = 21.22), compared to 48.49 years (SD = 20.32) in the extubation success group. The difference in age was not statistically significant.

Cumulative Fluid Input: Patients in the failure group had a slightly higher mean cumulative fluid input (12,452.11 mL, SD = 7504.34) compared to those who had a successful extubation (11,802.85 mL, SD = 9164.73). However, this difference was not statistically significant.

Duration of Mechanical Ventilation: The average duration of mechanical ventilation was comparable between the two groups, with a mean of 5.74 days (SD = 2.54) in the failure group and 5.76 days (SD = 2.61) in the success group. No significant difference was observed.

Cumulative Fluid Balance: Patients who experienced extubation failure had a higher mean cumulative fluid balance (1613.03 mL, SD = 2072.28) than those who were successfully extubated (1058.93 mL, SD = 1730.25). This difference, while not statistically significant in the descriptive analysis, showed significance in earlier inferential testing (p = 0.040), suggesting fluid balance may be an important factor in extubation outcomes.

Cumulative Fluid Output: Cumulative fluid output was similar between groups ie No significant difference was found.

Fluid Input/Output Ratio: The fluid input/output ratio was marginally higher in the failure group (mean = 1.16, SD = 0.150) than in the success group (mean = 1.13, SD = 0.150), though this difference was not statistically significant.

Among the extubation failure group, 22 were female and 44 were male. In the success group, 93 were female and 211 were male. A chi-square test indicated no significant association between gender and extubation outcome ($\chi^2 = 0.190$, df = 1, p = 0.663).

Primary disease distribution did not differ significantly between groups ($\chi^2 = 2.10$, df = 4, p = 0.717). While respiratory disease was the most common diagnosis overall, it was similarly distributed among success and failure groups (22 failures vs. 89 successes). Other conditions like cardiovascular, renal, neurological, and general/other were also proportionally represented.

Of the 66 patients who failed extubation, 29 underwent CPAP and 37 underwent T-piece trials.

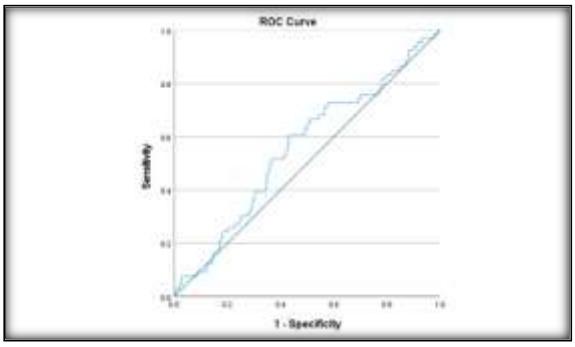
In the success group, 145 used CPAP and 159 used T-piece. No statistically significant association was observed between type of SBT and extubation outcome ($\chi^2 = 0.307$, df = 1, p = 0.579).

Diuretic use was recorded in 11 of the patients who failed extubation and in 63 of those who succeeded. The use of diuretics was not significantly associated with extubation outcome ($\chi^2 = 0.558$, df = 1, p = 0.455).

Dialysis was administered to 10 patients in the failure group and 35 in the success group. The chi-square test revealed no statistically significant relationship between dialysis requirement and extubation outcome ($\chi^2 = 1.02$, df = 2, p = 0.602).

Receiver Operating Characteristic (ROC) Analysis of Fluid Input/Output Ratio

To evaluate the predictive value of the fluid input/output (I/O) ratio in determining extubation outcomes, a Receiver Operating Characteristic (ROC) analysis was conducted. This analysis assesses the discriminative ability of the I/O ratio to correctly classify patients into extubation success or failure groups.



Area Under the Curve (AUC): The area under the ROC curve (AUC) for the fluid I/O ratio was 0.558 with a standard error of 0.039 and an asymptotic significance (p-value) of 0.140. The 95% confidence interval ranged from 0.482 to 0.634.

While the AUC is slightly above 0.5—suggesting some discriminative power—it is not statistically significant, as indicated by the p-value (> 0.05). This implies that the fluid input/output ratio does not provide a strong or reliable predictive signal for extubation outcomes in this sample population.

A specific cut-off value of 1.129 was evaluated. At this threshold:

- Sensitivity (true positive rate) was 56.91%
- Specificity (true negative rate) was 60.61%

These values indicate moderate classification performance. In practical terms, using an I/O ratio of 1.129 as a decision threshold would correctly identify approximately 57% of patients who would experience extubation failure and correctly exclude approximately 61% of those who would not. However, these rates are relatively modest and, combined with the non-significant AUC, suggest limited clinical utility of the I/O ratio as a standalone predictor.

In summary, none of the categorical variables—gender, primary disease, type of spontaneous breathing trial, diuretic use, or dialysis—were significantly associated with extubation outcomes. Among the continuous variables, cumulative fluid balance showed a statistically significant difference between groups in prior inferential analysis and may represent a critical factor influencing extubation success. Other clinical metrics, including age, fluid input/output, and mechanical ventilation duration, were not predictive of extubation failure in this sample.

The ROC analysis of the fluid input/output ratio demonstrated only marginal discriminative ability in predicting extubation outcomes, with an AUC of 0.558 and non-significant p-value (0.140). Although a cut-off value of 1.129 offered moderate sensitivity and specificity, the overall findings do not support the use of the I/O ratio as a sole predictive marker for extubation success or failure in this cohort. Future studies may consider incorporating this parameter into multivariate models alongside other clinical indicators to enhance predictive accuracy.

DISCUSSION

Extubation failure, a clinically significant complication associated with increased morbidity, mortality, and healthcare costs, was observed in 17.8% of patients in this cohort. Understanding factors that differentiate successful from failed extubation may help clinicians optimize timing and supportive care strategies in the ICU.

Demographic and Clinical Characteristics: The demographic profile of the study population aligns with existing literature, with a male predominance (68.9%) and a wide age range (mean ~48 years). No significant difference in age or gender was observed between the extubation success and failure groups, suggesting that demographic factors alone may not be reliable indicators of extubation readiness.

Primary diagnoses among patients included respiratory, cardiovascular, neurological, renal, and general/other conditions, with respiratory causes being the most common (30%). Importantly, primary disease distribution did not significantly differ between groups, indicating that underlying etiology alone may not sufficiently predict extubation outcomes. This finding supports the notion that extubation failure is likely multifactorial and not determined by diagnosis alone.

Fluid Balance and Mechanical Ventilation Parameters: While cumulative fluid input, output, and the input/output (I/O) ratio did not differ significantly between groups, cumulative fluid balance emerged as a statistically significant factor, with patients experiencing extubation failure exhibiting higher mean fluid balance than those who succeeded (1613.03 mL vs. 1058.93 mL, p = 0.040). This finding aligns with prior research suggesting that positive fluid balance may impair respiratory

function, particularly by contributing to pulmonary edema, impaired gas exchange, and respiratory muscle weakness.

Although the mean fluid I/O ratio was marginally higher in the failure group (1.16 vs. 1.13), this difference did not reach statistical significance. ROC analysis for the I/O ratio confirmed its limited discriminative power, with an AUC of 0.558 ($p = 0.140$), sensitivity of 56.9%, and specificity of 60.6% at a cut-off value of 1.129. These findings indicate that while a higher I/O ratio may reflect subclinical fluid retention, it is not a strong standalone predictor for extubation failure and should be interpreted in the context of cumulative balance and clinical presentation.

The duration of mechanical ventilation was not significantly different between groups, averaging around 5.7 days in both cohorts. This contrasts with some earlier studies that identified prolonged ventilation as a risk factor for extubation failure. The relatively short ventilation duration in both groups may reflect adherence to current weaning protocols and early extubation practices in the study setting.

Other Clinical Parameters: Use of diuretics, dialysis, and type of spontaneous breathing trial (SBT) also showed no significant association with extubation outcomes. While diuretics were more commonly used in the failure group, this did not reach statistical significance, and their effect on fluid status and respiratory recovery warrants further exploration in prospective studies.

Similarly, no significant differences were found between CPAP and T-piece SBT modalities in terms of extubation success. These findings are consistent with prior randomized controlled trials that have shown comparable outcomes between these SBT types in terms of predicting extubation readiness.

Clinical Implications: The findings of this study emphasize the importance of cumulative fluid balance as a modifiable factor potentially associated with extubation success similar to previous studies.[8] Although fluid input/output ratios and other individual fluid parameters did not reach statistical significance, net balance remains a critical integrative measure of patient volume status. Clinicians should consider adopting a conservative fluid management strategy in the peri-extubation period, particularly in patients at high risk for respiratory compromise.

Furthermore, the lack of association between extubation outcomes and other commonly assessed variables (age, gender, duration of ventilation, and SBT type) suggests that multifactorial risk assessment tools may be more appropriate than reliance on single parameters. These tools may include cumulative fluid metrics, in addition to hemodynamic stability, neurological status, respiratory muscle strength, and disease-specific factors.

CONCLUSION

This study highlights cumulative fluid balance as a significant factor associated with extubation failure in mechanically ventilated patients. Other variables, including fluid input/output ratios, mechanical ventilation duration, and spontaneous breathing trial type, did not show a significant association. These findings support a more nuanced, integrative approach to extubation readiness that includes assessment of fluid status alongside established clinical criteria.

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